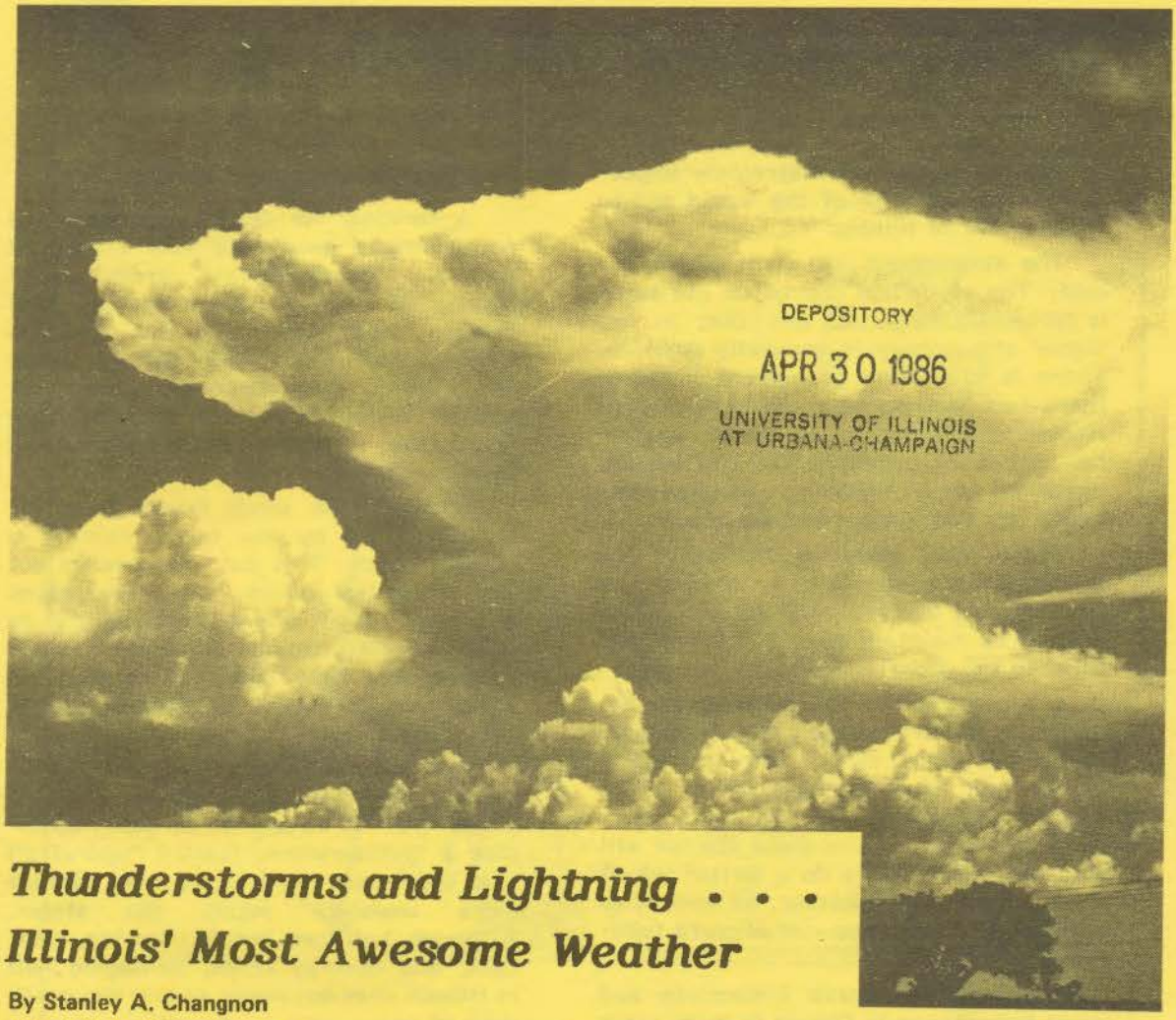


Thunderstorms and Lightning . . .
Illinois' Most Awesome Weather

By Stanley A. Changnon
Illinois State Water Survey

No other atmospheric event in Illinois carries with it the beauty, fear, and importance that thunderstorms produce. Thunderstorms are wonderfully complex natural machines that convert moisture and energy into rainfall, lightning, and many other severe weather phenomena that we all fear including tornadoes, heavy rainstorms, straight line winds, and hail.

The Importance of Thunderstorms

Thunderstorms are extremely important to the climate of the world and to the weather of Illinois.

The atmosphere is a giant global circuit. The electrical charge on the earth is generally negative and that in the higher atmosphere is generally positive. There is a leakage of current between these two "attracting forces." Thunderstorms help maintain the global electrical circuit by providing the connection, which we see as lightning discharges between the atmosphere and the ground.

These discharges in thunderstorms are occurring somewhere around the world during every minute of every day, helping to maintain the "electrical balance" in the global circuit.

Scientists at the Water Survey are attempting to unravel the great complexities of the global circuit since it greatly affects our understanding of how the weather and climate of the earth function. Breakthroughs in these studies will help us eventually to do a better job of predicting today's weather, as well as to understand better how our climate functions.

Thunderstorms have immediate and great importance to Illinois in many ways — and not just because they sometimes represent a threat to life and limb. Thunderstorms bring, on the average, 70% of all the annual precipitation received in the state. In the summer months of June, July, and August, thunderstorms produce 90% of all rainfall.

In light of these facts, thunderstorms are very critical and essential to the hydrologic cycle and thus to the water resources that the state of Illinois enjoys.

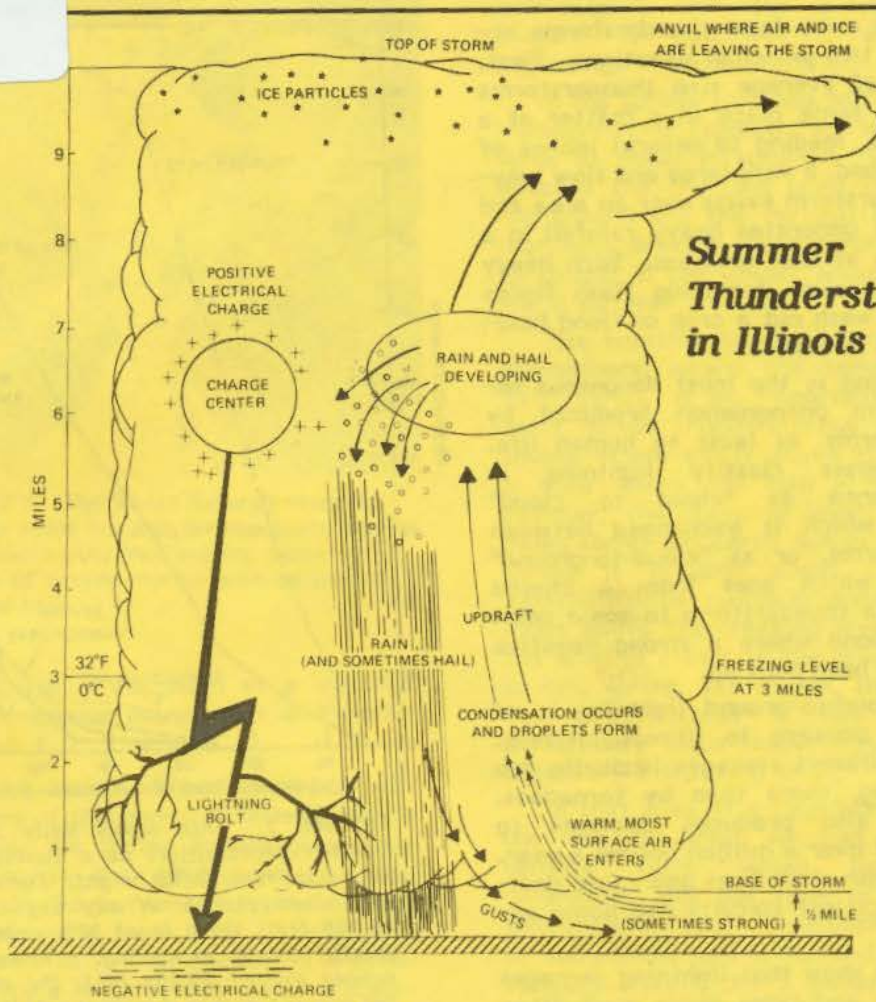
The Thunderstorm As A Threat

A forecast for severe thunderstorms causes many people to feel somewhat uneasy. Thunderstorms produce all forms of what meteorologists call "severe local storms." This includes straight line winds that damage crops and property, hail that ruins crops, tornadoes, heavy rains that lead to flash floods, and lightning-induced deaths and fires.

Straight line winds result from air brought down by the heavy rain in a thunderstorm. This cold air sweeps out of a storm and reaches the ground, often at a high speed, where it spreads out as a strong gust capable of doing damage to property and trees. Straight line winds can be nearly as destructive as tornadoes.

Hail is formed high aloft in thunderstorms by raindrops that are frozen. These grow if strong winds going up inside a thunderstorm (called "updrafts") hold the stones aloft where they capture more moisture inside the storm. Although hail can break windows, dent cars, and destroy crops, damaging hail in Illinois does not occur at any one place very often.

Tornadoes often grow along the south flanks of thunderstorms when volatile unstable weather conditions with fast moving frontal systems somehow lead to the rotation of winds inside or alongside a thunderstorm, and to the formation of a funnel. People who live in Illinois are aware of the great destruction of life and property that a severe tornado can cause, but as with hail, tornadoes do not occur frequently at any one place.



Summer Thunderstorm in Illinois

Those Wonderful Weather Machines!

The workings of a mature thunderstorm reveal its complex machinery. Initially air flows into the cloud bottom bringing heat and moisture. The ascending air passes by the freezing level but the moisture does not freeze right away and becomes "supercooled." Ice particles appear about a mile above the freezing level. These particles capture the water and begin to grow, collide, and form raindrops. At this stage electrical charges appear on the droplets and eventually "charge centers" develop. These in turn lead to lightning discharges, sometimes within the cloud, or between clouds, or to the ground as shown. In this manner the strokes release the electrical energy accumulated in the clouds.

Once the rain process has begun, a shaft of cold rain descends rapidly. It literally drags cold air from aloft in the storm downward to the ground. This "downdraft" is dangerous to aircraft landing and taking off, and as this air reaches the ground, it fans out and can be very damaging if the storm is large and moving fast.

Hail is an occasional by-product of the up-down cycle. If the updraft is strong, the small mushy ice balls in the "rain factory zone" are suspended, allowing them to freeze, and they form multiple layers as new upward surges of air furnish the moisture for growth. When their weight exceeds the updraft strength, down comes a volume of hail mixed in with the rain.

Heavy rains from thunderstorms occur from two principal situations. First, a series of average size thunderstorms cross the same place in a matter of a few hours, leading to several inches of rain. Second, a very large and slow moving thunderstorm exists over an area and the storm generates heavy rainfall in a few hours at that location. Such heavy rains can cause damaging flash floods that may wash out a crop or flood basements and streets.

Lightning is the most dangerous severe storm phenomenon produced by thunderstorms, at least to human life. Meteorologists classify lightning in thunderstorms as "cloud to cloud" lightning which is exchanged between thunderstorms, or as "cloud-to-ground" lightning which goes from a charge center in a thunderstorm to some point at the ground where a strong negative charge has been built up.

The cloud-to-ground lightning is of particular concern to Illinois citizens. Each year Illinois averages 10 deaths due to lightning, more than by tornadoes. Lightning also produces damages to property of over a million dollars a year. Lightning can start fires and cause damage to electrical circuits and home appliances.

Records show that lightning damages to property and trees occur most often in rural areas. The density of buildings in major metropolitan areas collectively help to cause leakage of charge between the earth and the atmosphere. But in rural areas, there is greater prevalence of cloud-to-ground lightning that hits structures like farm houses, barns, churches, and schools.

Lightning protection, such as lightning rods, in rural areas is an important consideration for rural structures. Later in this brochure we will talk about "what to do about lightning" as well as other threats from thunderstorms.

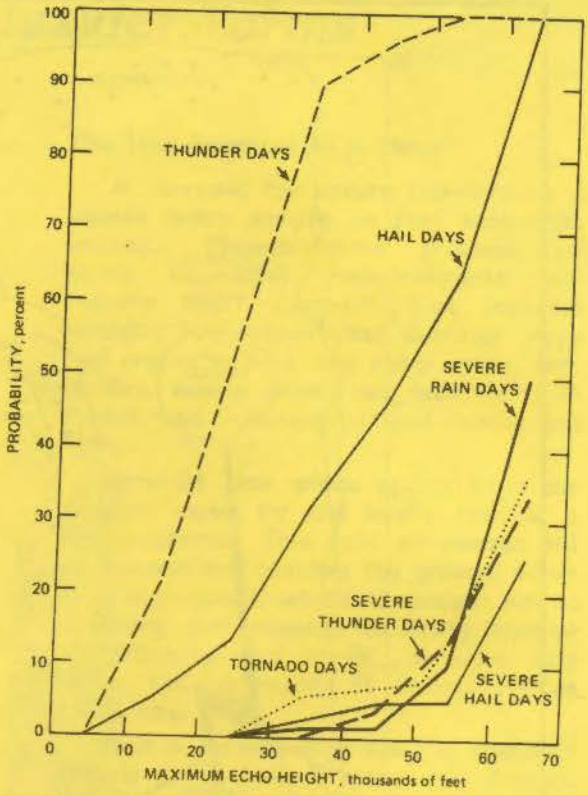


FIGURE 1. This shows daily severe weather probabilities as a function of maximum radar echo height. For example, when echoes on any day exceed 30,000 feet, there is an 80% chance of thunderstorms occurring. When the echoes exceed 50,000 feet, the chance for severe weather increases rapidly.

What Are Thunderstorms?

Thunderstorms are very large cumulus clouds that by definition lead to lightning discharges. It is the sudden tremendous heat from the lightning stroke that causes the shock waves that we hear and refer to as "thunder." A

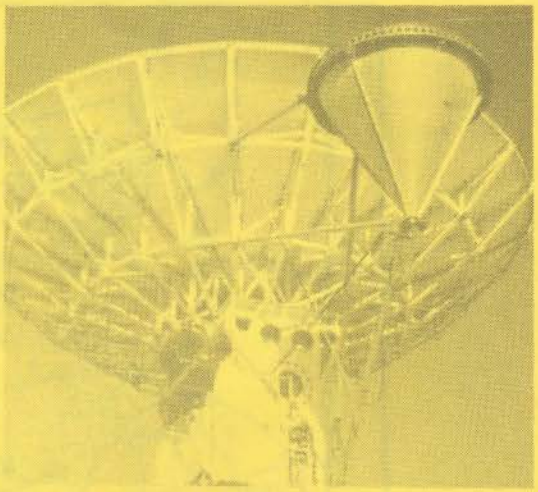


FIGURE 2. The Water Survey's research weather radar has doppler capability and dual wavelengths that provide better detection of severe storms such as tornadoes and hail.

thunderstorm is recorded at a weather station if one or more peals of thunder are heard.

A Look Inside. Visual and radar observations of thousands of thunderstorms studied by the Water Survey give great insight as to the dimensions of these storms. In the summer, a typical Illinois thunderstorm is from 8 to 12 miles tall and about 8 to 15 miles wide. It is often shaped like a large cylinder with a diameter about the same size as its height.

A radar cross section of the inside of a thunderstorm will show varying rain intensities. High intensities indicate heavy rain rates and sometimes indicate hail. Figure 1 reveals that the height of thunderstorm echoes relates to storm production on a given day. When echoes exceed 50,000 feet in Illinois and other parts of the Midwest, the probability of severe hail or tornadoes increases greatly. Radars with doppler capability and multiple wavelengths like the Survey's radar (Figure 2) can better detect the beginnings of tornado and hail conditions.

In the spring, fall, and winter seasons, thunderstorms typically are not quite as large as those in summer. This results because the freezing level is closer to the ground and the vertical air motions that help develop thunderstorms are not as strong in the colder seasons as they are in summer.

The freezing level, that level of the atmosphere where the temperature is 32°F (0°C), is an important reference point in our thunderstorms. Much of a thunderstorm exists above that level in a zone where the rain is formed. In summer, the freezing level is about 3 miles above the earth, but in the fall and spring it is only about 1 mile up. Thunderstorms typically extend 4 to 8 miles above the freezing level. Thus, if the level is closer to the ground, as it is in fall, spring, and winter, the height of the thunderstorm is not as great, particularly since there is much less of it below the freezing level.

In that area of a thunderstorm above the freezing level, we find the charge centers from which lightning is generated, and the zone of the storm where upcoming air is condensed and rain or sometimes hail is formed. This zone ranging from 1 to 3 miles above the freezing level is truly the "rain factory" of a thunderstorm. It is also a very dangerous place for any aircraft to fly because it is an area of strong air motions and large volumes of water, ice, hail, and lightning.

What Feeds The Storm? A thunderstorm can be thought of as a large cloud machine that behaves like a vacuum cleaner. A thunderstorm feeds on warm air and moisture, and much of the air is pulled up from near the ground.

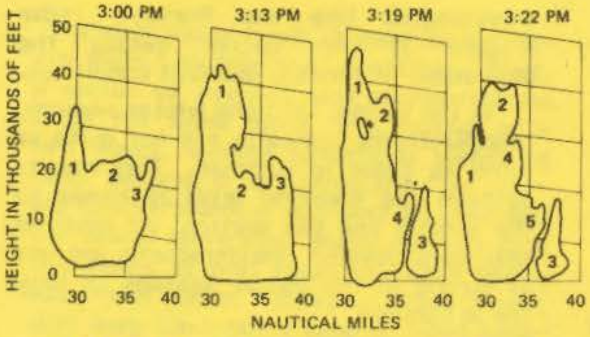


FIGURE 3. Radar cross sections through a thunderstorm show the growth and dissipation of 5 convective cells inside the storm during a little over 20 minutes.

As a cumulus cloud grows (see Figure 3), it entrains warm moist air near the surface. As this air rises, the cloud grows vertically and the moist humid air inside condenses to form tiny cloud droplets.

As the cloud grows higher and goes above the freezing level, some of this moisture is converted to ice particles and large water drops, both of which lead to the formation of rain. Sometime after the cloud goes above the freezing level, we begin to find the development of electrical charges inside the cloud. When these become strong enough, lightning discharges occur. Then we have a thunderstorm.

The size, duration, and violence of a thunderstorm are partially determined by its source of warm moist surface air. If there are large amounts of this available, and nothing limiting the vertical growth of the thunderstorm in the atmosphere, the storm can grow rapidly (10 minutes to go 2 miles up) and reach very tall heights.

Some thunderstorms in Illinois have tops of 12 to 13 miles above the surface. If the supply of air and the wind field aloft that is pushing a storm do not change, a thunderstorm can last 3 or 4 hours and travel 100 miles. However, most thunderstorms in Illinois last from 30 to 90 minutes and cover anywhere from 20 to 50 miles in their lifetimes. Thunderstorms typically consist of 3 or more active cells (a cell is a rising column of air and moisture), with one cell dissipating, one at maturity, and one or more youthful cells growing along its flanks.

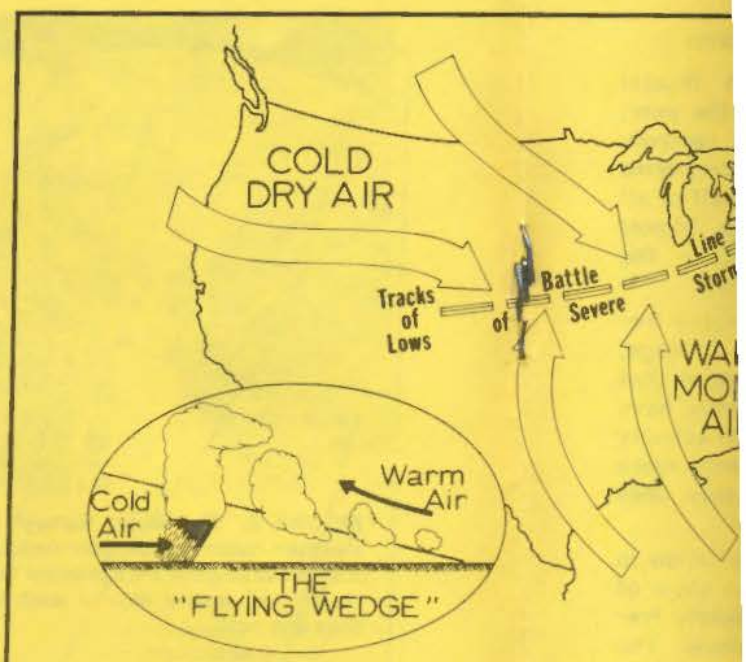


FIGURE 4. How conflicting air masses meet, with cold air the warm moist air and often producing severe thunderst eastern two-thirds of the U.S.

Meteorological Factors Causing Thunderstorms

Most thunderstorms need a good supply of warm moist air near the ground, but clouds will not develop into thunderstorms unless there are other key atmospheric conditions present. Fronts,

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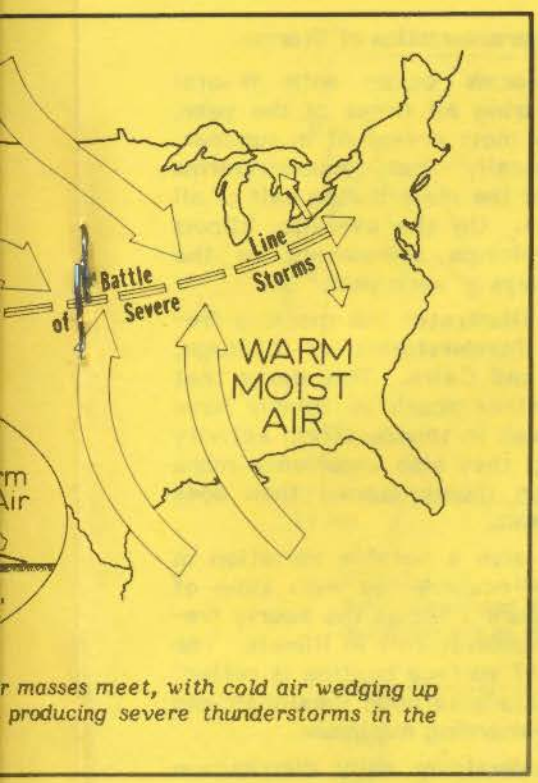


r masses meet, with cold air wedging up producing severe thunderstorms in the

which are the boundaries between air masses of differing temperature and moisture both at the surface and aloft, are a primary place where thunderstorms occur. Why?

Meteorologists know that fast or slow moving air masses (see Figure 4), wedging into other air masses, are the major triggers of changes in vertical motions of the atmosphere. A cold front simply represents where a wedge of cold air is hitting warmer (usually more moist) air. Along its often wiggly edge, the cold air lifts the warm air and helps trigger cumulus clouds and then thunderstorms. Thus, we generally have an atmospheric disturbance extending over hundreds of miles to get thunderstorms in Illinois. Often they are cold fronts, but other times they are warm fronts.

Quite often our most violent thunderstorms come with "squall lines." A squall line is a rapidly moving, organized line of active thunderstorms typically 100 to 150 miles ahead of a cold front. The squall line forms as the warm unstable air ahead of the cold front is forced rapidly upward. Illinois typically has 10 to 15 squall lines a year and they always produce thunderstorms. Furthermore, many of these squall line storms produce severe weather such as tornadoes. Figure 5 shows radar echoes aligned along a squall line.

Some thunderstorms occur without frontal passages. They are labeled "air mass thunderstorms." These occur on a few days during the summer as a result

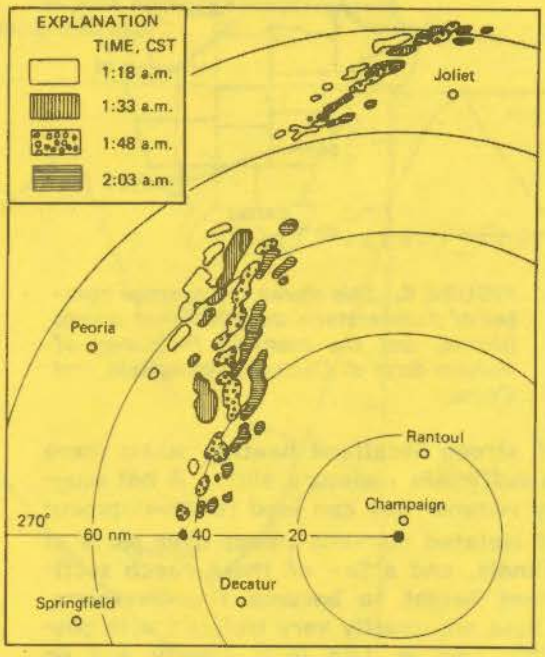


FIGURE 5. Radar echoes aligned along a squall line showing a time sequence in one storm. Squall line thunderstorms usually bring severe weather.

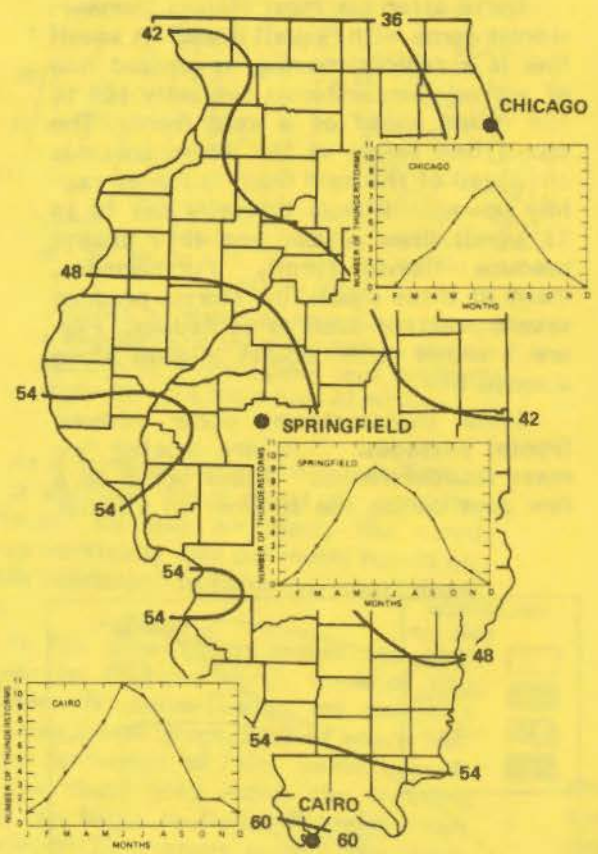


FIGURE 6. This shows the average number of thunderstorm days in a year across Illinois, and the monthly frequency of thunder days at Chicago, Springfield, and Cairo.

of strong localized heating when there is sufficient moisture aloft. A hot muggy summer day can lead to development of isolated cumulus clouds over parts of Illinois, and a few of these reach sufficient height to become thunderstorms. These are usually very isolated with possibly one or two in a county and no others in Illinois. They do not persist very long. As soon as the atmosphere starts cooling off in the late afternoon, air mass thunderstorms begin to die.

Temporal Characteristics of Storms

Thunderstorms occur with frontal conditions during all times of the year, but they are most prevalent in summer. Illinois typically has thunderstorms somewhere in the state during half of all summer days. On the average, Illinois has thunderstorms somewhere in the state on 90 days of each year.

Figure 6 illustrates the monthly frequency of thunderstorms at Chicago, Springfield, and Cairo. This shows that locations farther south in Illinois have an earlier peak in thunderstorm activity in the spring; they also experience more winter season thunderstorms than does northern Illinois.

There is also a notable variation in thunderstorm occurrences with time of the day. Figure 7 shows the hourly frequency of thunderstorms in Illinois. The importance of surface heating is reflected in the late afternoon maximum and the cool mid-morning minimum.

The thunderstorm daily distribution also shows a tendency for a second peak of nocturnal (night-time) thunderstorms. An increase in the low-level winds often occurs in the central plains during the summer night-time hours. This wind pattern, or low-level jet as it is often called, can lead to the initiation of thunderstorms in the central Midwest during the late night hours. Thus Illinois, and particularly the western sections of the state, experiences a secondary peak of thunderstorm activity during those hours.

Another dimension of the temporal aspect of thunderstorms is their frequencies over long periods. Figure 8 shows the number of days with thunderstorms at two weather stations in or near Illinois over the 80-year period from 1901 through 1980. In the northern part of the state, thunderstorms have been gradually

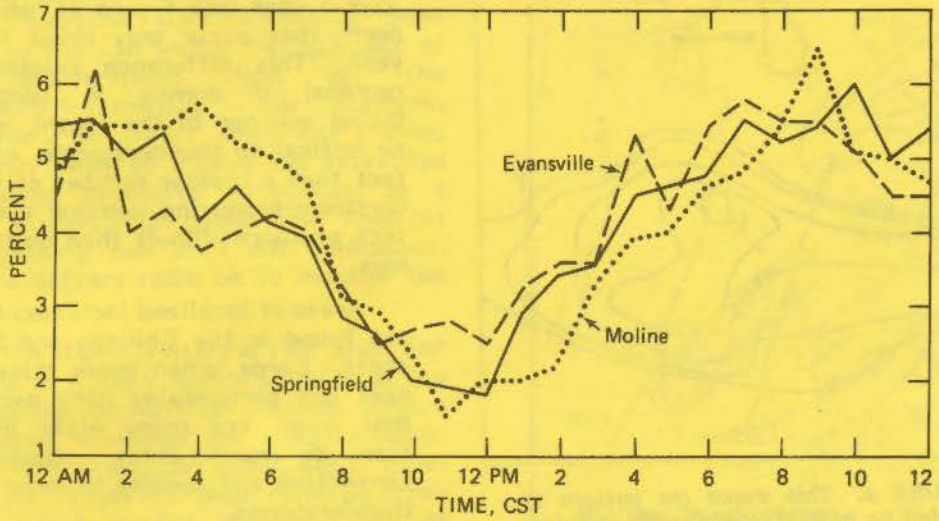


FIGURE 7. Hourly occurrences of thunderstorms at Moline, Springfield, and Evansville, Indiana. The peak hours for thunderstorms in Illinois are in late afternoon and early evening.

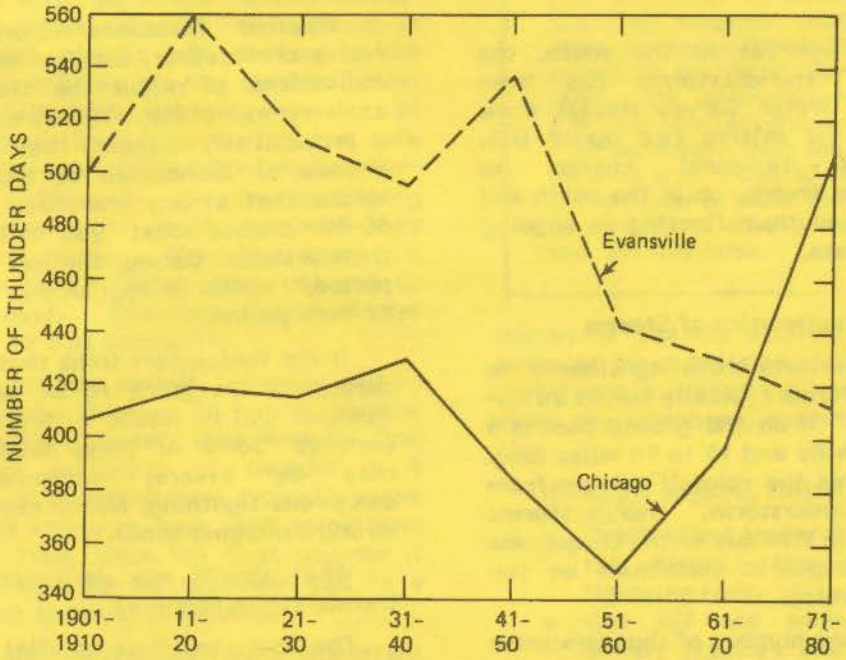


FIGURE 8. Thunderstorm frequencies over 80 years at Chicago, representing northern Illinois, and at Evansville, Indiana, representing southern Illinois. The recent increase in thunder days in the north and decrease in the south are indicated.

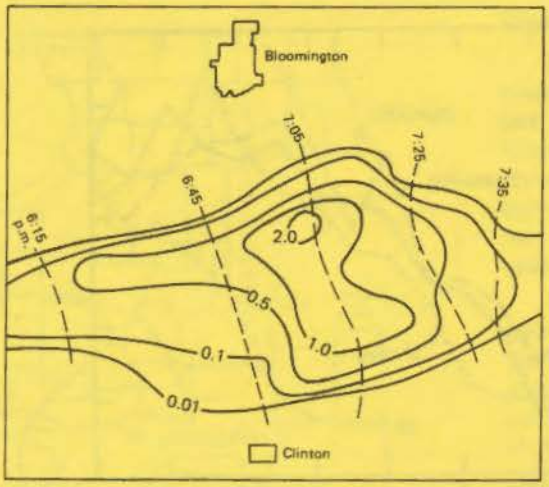


FIGURE 9. This shows the pattern of rainfall (in inches) from a single thunderstorm which lasted a little over 1¼ hours. The area of the heaviest rain (1 to 2 inches) also had hail.

increasing, whereas in the south, the number of thunderstorms has been decreasing. Water Survey studies show that Illinois is astride two major U.S. regions of temporal change in thunderstorm trends, up in the north and down in the south, reflecting an ongoing shift in climate.

Spatial Characteristics of Storms

A thunderstorm traveling alone or in a group of storms typically leaves an imprint of rainfall on the ground that is 5 to 10 miles wide and 10 to 50 miles long. Figure 9 shows the rainfall pattern from a single thunderstorm. Thunderstorms vary greatly in size due to the uniqueness of the atmospheric conditions on the days they develop.

The average number of thunderstorms that occur across the state varies greatly. In the southern part of Illinois thunderstorms occur on an average of 60 days a year (see Figure 6), while in the north they occur only about 40 days a year. This difference relates to the regional difference in temperatures (being warmer in the south), which are so critical to thunderstorms, and to the fact that a greater number of the thunderstorm-producing weather systems affect southern Illinois than northern Illinois.

Areas of localized increases in storms are found in the Chicago and St. Louis areas. Large urban areas release more heat and particulates (tiny particles of dust, soot, and many other materials) than do rural areas, causing more convection and leading to more summer thunderstorms.

What To Do About Thunderstorms and Lightning

Weather forecasts issued by the National Weather Service will contain indications of when the thunderstorm activity will occur. This is expressed in a probabilistic manner, that is, "a 50% chance of thunderstorms today." This means that at any one place there is a 50-50 chance that you will have a thunderstorm during the set "forecast period," which is typically a 6-hour or 12-hour period.

If the forecasters think that the thunderstorms are going to be severe, the forecast will be issued with a statement such as "Some of these thunderstorms may be severe, accompanied by dangerous lightning, heavy rain, hail, or strong damaging winds."

What should one do in relation to thunderstorm dangers?

The first step is to be alert and keep monitoring the forecasts on radio or television. NOAA weather radio stations on FM now cover all areas of Illinois and

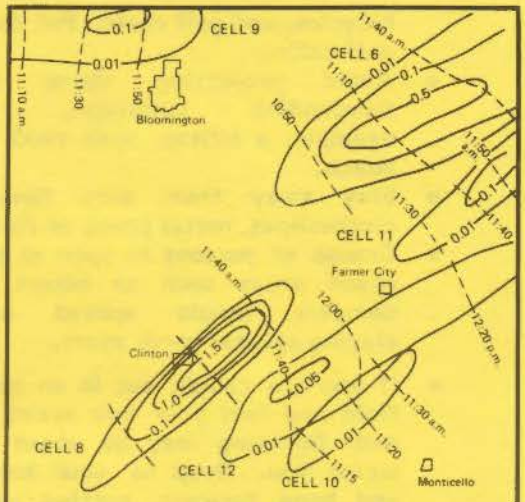
provide continuous weather information. Some television stations display radar maps so you can watch the approach of the thunderstorm cells on the television-transmitted radar patterns. [However, in violent electrical storms, you may wish to unplug the television and other expensive appliances, as a surge of electrical power over lines hit by lightning can burn out appliances. Keep a battery radio on to monitor the storm.]

If the storm is nearing your area, and especially if very severe conditions are developing, the National Weather Service will issue **"warnings"** for specific conditions (high winds, tornadoes, etc.). However, the danger will most often be lightning, which is the leading cause of weather-related deaths in the U.S. each year.

Most lightning danger relates to outside activities, whether it's working in the garden, playing golf, working on the farm, or children playing outside. Most people killed by lightning are out of doors where they assume they are safe before the approach of existing thunderstorms. However, newly developing thunderstorms in clouds overhead may begin to produce lightning that will threaten people before they can get to proper cover. Everyone should always be alert to that possibility.

If conditions permit, lightning will be seen before thunder is heard because light travels faster than sound. The maximum audibility of thunder is 6 miles, and thunderstorms typically move 20 to 30 miles an hour, and sometimes faster. Thus, once the first thunder is heard, lightning can be near you in a matter of minutes or seconds.

So, the second and most important step when a thunderstorm threatens is **to seek shelter.** If you are at home, stay



Multiple Thunderstorms

Here we see patterns of rainfall (in inches) from a series of thunderstorms on a summer day. The data are from a network of 200 recording raingages (each 3 miles apart) in central Illinois that was operated by the Water Survey for 15 years. The thunderstorms vary in size and are elongated, reflecting their movement from the west. The patterns show cores of heavier rain in the center of these thunderstorms. Localized hail also occurred in or near the rain cores.

inside. If you are outside, get inside a home or large building, or inside an all-metal (not a convertible) vehicle. Avoid using the telephone, except in emergencies.

If caught outside, follow these rules:

- Don't stand under trees or other tall objects — they act as natural lightning rods.
- Get off and away from open water, tractors and other metal farm equipment, or small metal vehicles such as motorcycles,

bicycles, and golf carts. Put down golf clubs.

- Avoid projecting above the surrounding landscape, for example, a hilltop, open field, or beach.
- Stay away from wire fences, clotheslines, metal pipes, or rails.
- Groups of persons in open or exposed areas such as hikers or campers should spread out, staying several yards apart.
- If you are caught out in an open field and feel your hair stand on end, lightning may be about to strike you. Drop to your knees and bend forward, putting your hands on your knees. DO NOT lie flat on the ground.

Where to Get More Information

The Illinois State Water Survey has made extensive studies of thunderstorms. If you desire more information about these storms, please write to: **Illinois State Water Survey, 2204 Griffith Drive, Champaign, Illinois 61820.** Please indicate what additional information concerning thunderstorms you would like to have.

If you desire more information about thunderstorm forecasts or what to do for protection in relation to thunderstorms, you can contact the National Weather Service Forecast Office, O'Hare Office Building #2, Room 610, 10600 W. Higgins Road, Rosemont, Illinois 60018.

This is the eleventh in a series of pamphlets describing in popular language our research findings about water resources and weather in Illinois and current issues concerning them.

December 1985

Stanley A. Changnon is a climatologist and Chief Emeritus of the Illinois State Water Survey. This brochure is based in part on his numerous studies concerning severe weather phenomena. Some of the information included was taken from materials supplied by the National Oceanic and Atmospheric Administration, National Weather Service.

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